Mon. Not. R. Astron. Soc. **000**, 1–5 (2008) Printed 9 March 2008 (MN LATEX style file v2.2)

VV124 (UGC4879): A new transitional dwarf galaxy in the periphery of the Local Group

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9 March 2008

ABSTRACT
We present the first resolved-star photometry of VV124 (UGC4879) and find that this is the most isolated dwarf galaxy in the periphery of the Local Group. Based on imaging and spectroscopic follow up observations with the 6m BTA telescope, we resolve VV124 into 1560 stars down to the limiting magnitude levels of $V \simeq 25.6$ and $I \simeq 23.9$. The young blue stellar populations and emission gas are found near the core, but noticeably displaced from the center of the galaxy as traced by dominant evolved red stars. The mean radial velocity derived from the spectra of two Blue Supergiant stars, an HII region and unresolved continuum sources is -80 ± 10 km/s. The evolved "red tangle" stellar populations, which contains the red giant branch (RGB), are identified at large galactocentric radii. We use the I-band luminosity function to determine the distance based on the Tip of RGB method, 1.1 ± 0.1 Mpc. This is ~ 10 times closer than the values usually assumed in the literature, and we provide revised distance dependent parameters. From the mean $(V-I)$ color of the RGB, we estimate the mean metallicity as [Fe/H]$\simeq -1.37$ dex. Despite of its isolated location, the properties of VV124 are clearly not those of a galaxy in formation, but rather similar to a transitional dIrr/dSph type.

Key words: galaxies: dwarf – galaxies: individual: VV124 (UGC4879) – galaxies: Local Group – distances and redshifts – stellar content

1 INTRODUCTION

The star formation and chemical enrichment histories (SFH) of the Local Group galaxies, which can be derived from their resolved stellar populations, directly test cosmological galaxy formation models. However, the dynamical and mass loss histories of the nearest satellite galaxies are the major uncertainty in understanding their evolution (e.g., Mayer et al. 2006). Isolated dwarf galaxies are not affected by these environmental effects, and are therefore ideal probes of the basic mechanisms affecting the SFH of a galaxy. Galaxies in the periphery of the Local Group (LG) are particularly valuable in this respect, being the only *isolated* systems for which detailed information is possible on their complete SFH with the Hubble Space Telescope (HST; Gallart & the LCID Team 2007). Additionally, these fringe dwarfs are important probes of the dynamical state of the local universe(van der Marel & Guhathakurta 2008). The purpose of this Letter is to announce the discovery of an additional exceptionally isolated galaxy in the outskirts of the LG.

One of the authors (AIK) has noticed a discrepancy between the distance based on adopted radial velocity of VV124 (UGC4879), $V_h = 600$ km s^{-1}, cited in both the NED and HyperLeda databases, and the galaxy's apparent resolution into stars on the Sloan DSS images. The bright blue stars are well distinguished near the center of VV124, while a few dozen fainter red objects can be traced to large galactocentric distances. Assuming this field population is composed of red giant (RGB) and asymptotic giant branch (AGB) stars, we made a preliminary estimation of VV124 distance as $D \leqslant 2$ Mpc.

This object is one of the Vorontsov-Veliaminov galaxies listed in his "Atlas and Catalog of Interacting galaxies" (Vorontsov-Veliaminov 1959) as a "Nest" type. Later the galaxy was included in Zwicky et al.'s (1968; UZC) and Nilson's galaxy catalogs (1973; UGC). The later catalog noted a presence of "several faint very blue condensations superimposed" in the object. Jansen et al. (2000) described VV124 as a low-luminosity dwarf that "shows the enhanced Balmer absorption lines and blue continuum of a young 'poststarburst' galaxy."

The radial velocity measurement of $V_h = 600 \pm 100$ km s^{-1}for VV124 comes from the first CfA redshift catalog (Huchra et al. 1983), that was reproduced in the RC3 catalog with uncertainty of 50 km s^{-1}, and currently cited in both NED and HyperLeda databases with a note on alternative measurement in UZC

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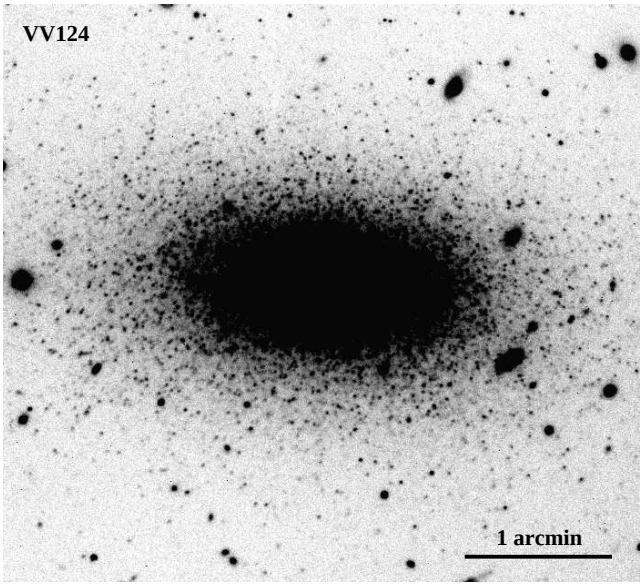

Figure 1. Image covering a $4.3' \times 4.3'$ region centered on VV124 made from the 6m telescope data in V band. North is up, and east is to the left.

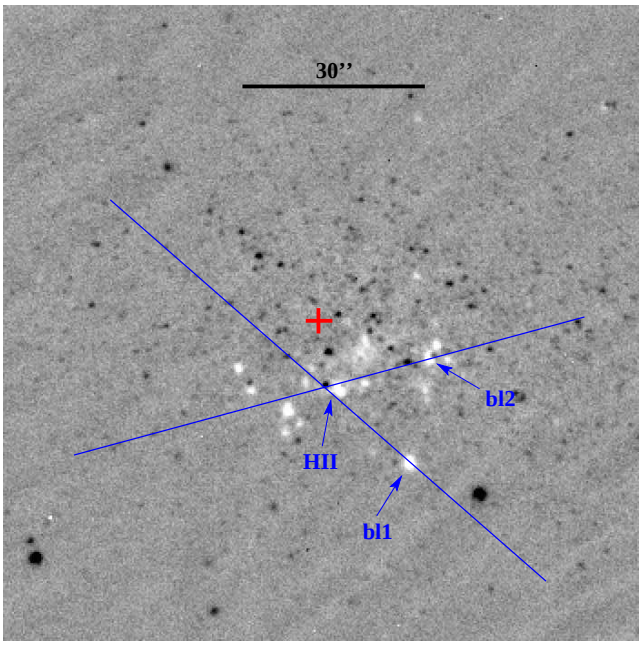

Figure 2. The distribution of blue (in white) and red stars (in black) in the central $1.5' \times 1.5'$ area, obtained by division of I-to-V band images. The lines mark the slit positions for the spectroscopic observations. The red plus sign shows the center of VV124. Two analyzed Blue Supergiant stars, and an HII region are indicated.

(Falco et al. 1999), $V_h = 62 \pm 69\,\mathrm{km\,s^{-1}}$. The revised 2002 version of UZC gives $V_h = -44 \pm 69\,\mathrm{km\,s^{-1}}$, derived via cross-correlation of the spectra obtained with the help of the FAST spectrograph on the 1.5m Tillinghast telescope. This measurement however remained unnoticed, and the galaxy was even considered by Azzaro et al. (2006) as a distant companion of NGC2841, which has a Cepheid distance of ~ 14 Mpc (Macri et al. 2001; Saha et al. 2006). VV124 is undetected in HI (Schneider et al. 1992), probably due to the survey's search range, $100 - 6800\,\mathrm{km\,s^{-1}}$. Another possible reason behind the lack of concerns over the VV124 distance, is a relatively high surface brightness, $\mu_{B_{25}} = 23.55$, for its new distance-corrected luminosity, $M_B = -11.6$ –about 1.5 mag above the value expected from the empirical absolute magnitude versus surface brightness relationship (e.g, Karachentsev et al. 2004). Various optical (Jansen et al. 2000; Taylor et al. 2005) and near-IR imaging surveys (Grauer et al. 2003) aimed at the global photometric parameters and also missed an apparent high degree of VV124 resolution.

2 OBSERVATIONS AND STELLAR PHOTOMETRY

Follow-up imaging observations of VV124 were obtained on 2008 January 10/11 using the SCORPIO (Spectral Camera with Optical Reducer for Photometrical and Interferometrical Observations; Afanasiev & Moiseev 2005) mounted at the prime focus of the 6m BTA telescope of the Special Astrophysical Observatory (Russia). The detector was a EEV42-40 2048×2048 CCD array with a field of view roughly 6×6 arcmin and a scale of $0.357''$ per 2×2-binned pixel. VV124 was observed with 3×200&3×60 s in V and 2×200&3×60 in I broad-band filters close to the standard Johnson-Cousins photometric system. The weather conditions were good, with a stable seeing of $1.0 - 1.1''$. The primary data reduction was performed using the ESO-MIDAS software package. It included de-biasing, flat fielding and cosmic-ray hit removal.

Figure 1 shows a coadded image from these data, exhibiting many resolved stars. The image of the central part of the galaxy obtained by division of I-on-V-band frames is shown on Fig. 2, and it demonstrates a slight asymmetry in the distribution of the blue stars (white on the figure) relative to the red stars, which can be traced to large galactocentric distances.

We performed single-star photometry with DAOPHOT II (Stetson 1987). Because of relatively strong image aberrations of the SCORPIO camera, we carefully selected isolated stars suitable to model the point-spread function (PSF), and removed stars from the detection catalog located in the areas where the PSF reconstruction was inadequate. The absolute photometric calibration of the data was performed using the observations of standard stars from the lists by Landolt (1992) on the same nights. We corrected data for foreground extinction in the direction of VV124 using the values of Schlegel et al. (1998): $A_V = 0.050$ and $A_I = 0.029$. We did not correct for internal extinction within VV124, but the transparency of the outer field stellar population (the population from which we derive the distance) is high and suggests that the extinction is low at large galactocentric radii.

The color-magnitude diagram (CMD) of VV124 (Fig. 3) illustrates a stellar mix that is characteristic of the superposition of many stellar generations, and reminiscent of the CMD of a typical transitional –intermediate dIrr/dSph galaxy like Phoenix or LGS3 (Gallart et al. 2004; Gallart & the LCID Team 2007). The "blue plume" at $(V-I) \sim 0$ contains massive blue supergiants and main-sequence stars, the "red plume" at $(V-I) \sim 1.5$ contains evolved giants and asymptotic giant branch (AGB) stars, while the "red tail" extending past $(V-I) > 2$ contains intermediate-mass AGB stars in the thermally pulsing phase, and the concentration of stars below the TRGB at $I \simeq 21.2$ contains low-mass red giants (RGB) and AGB stars. For reference, we overlay the CMD with the Z=0.001 BaSTI stellar isochrones (Pietrinferni et al. 2004) assuming the distance derived below. The blue plume is quite scarce, whereas the RGB exhibits a significant width. The stellar crowding and blending, as well as a fluctuation of internal extinction, may

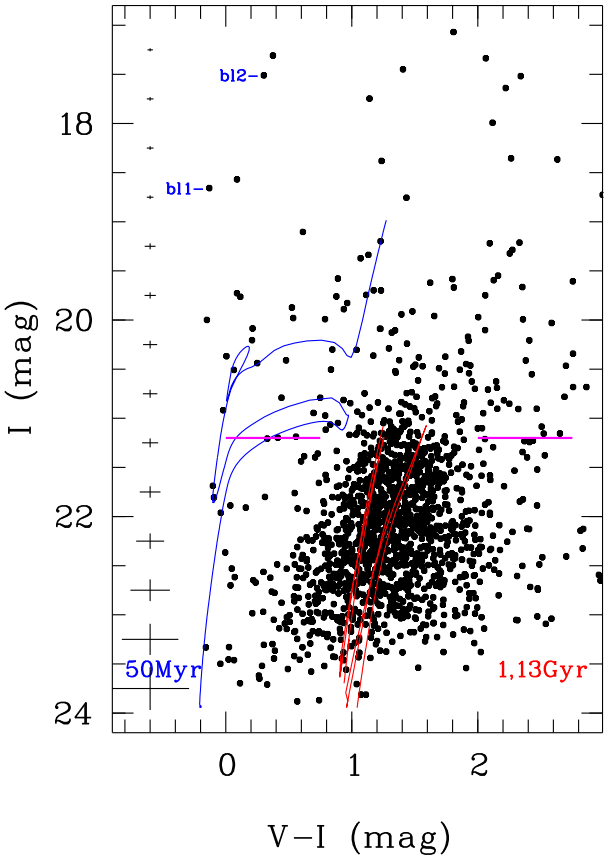

Figure 3. Color-magnitude diagram, $V-I$ vs. I, of the VV124 resolved stars, based on 6-m BTA imaging data. The error bars show the binned mean standard errors of the photometry. The Tip of the first ascent Red Giant Branch (TRGB) is marked with 2 horizontal lines. The isochrones are for the metallicity $0.001\,Z\odot$.

dominate these effects. However based on preliminary artificial star tests, the RGB width exceeds that photometric errors, suggesting a possible wide range of stellar metallicities and/or ages.

3 DISTANCE AND METALLICITY

We used our stellar photometry data to find the TRGB and to determine the distance and metallicity of VV124 (following Lee et al. (1993)). The photometric data of outer stars are preferable over the central high stellar density region since they exhibit much less crowding and fewer AGB stars, which tend to have a stronger concentration towards the center of irregular galaxies (Tikhonov 2005, 2006). Therefore, for the analysis of the RGB we exclude the innermost region defined by a central circle with diameter of $90''$. There is a sufficiently large number of stars detected in the selected area to have $0.7 < (V-I)_0 < 2.0$. The TRGB was found by applying a Sobel filter to the I-band luminosity function; it occurs at $I_0 = 21.17 \pm 0.10$ (indicated in Fig. 3 by a line). In order to estimate the average metallicity of the RGB stars we measure the color at half a magnitude below the TRGB, $(V-I)^0_{-3.5} = 1.43$, corresponding to the $(V-I)^0_{TRGB} = 1.63$. Based on the calibration by Lee et al. (1993) we estimated the metallicity of RGB stars of [Fe/H]$= -1.37$, and a distance of $D = 1.1 \pm 0.1$ Mpc.

Note that the result on the metallicity is based on the assumption that the age of the RGB stars is predominantly old, since the calibration of Lee et al. (1993) is based on old galactic globular clusters, therefore, if the majority of stars are younger than $10-13$ Gyr, this metallicity estimation is an upper limit of an intrinsic value.

4 SPECTRAL OBSERVATIONS

Long-slit spectral observations of VV124 were obtained with the same 6m/SCORPIO facility on 2008 February 6/7 in a wavelength range of $4000-5600$ Å with spectral resolution of 5 Å. Two $1''$-width long slits were placed on two bright blue stars near the center of the galaxy, marked on Fig. 2 as 'bl1' and 'bl2'. With the VV124 distance of 1.1 Mpc, the scale along the slit corresponds to 5.3 pc/$''$. This gives a separation of 111 pc between stars 'bl1' and 'bl2'. Both slits run over the compact HII-region, while the second one also includes by chance a high-redshift background galaxy.

The spectral data have been reduced using the standard calibration procedures within the IDL environment. The uncertainty of the wavelength calibration is 10 km s^{-1}. However, the final accuracy of the radial velocity measurements was limited by the quality of the spectrum of each of the detected components.

By matching the spectra of the two bright stars with the template spectra from the STELIB stellar library (Le Borgne et al. 2003, http://www.ast.obs-mip.fr/article181.html), we find that both stars are Blue Supergiants (BSG) of spectral type O9.5 for 'bl1', and F5Ia ('bl2'). HD30614 (α Cam, O9.5Iae) and HD188209 (O9.5Ib) are good matches for the star 'bl1', and the spectrum of HD269697 (F5Ia) from the Large Magellanic Cloud is a close match of that of 'bl2'. From the results of our stellar photometry we find that 'bl1' has $V = 18.53$ and $(V-I) = -0.13$, while magnitude and color of 'bl2' are $V = 17.81$ and $(V-I) = +0.30$. This corresponds to absolute magnitudes of $M_V = -6.73$ and $M_V = -7.45$ for 'bl1' and 'bl2', respectively.

To measure the radial velocities, we used absorption lines of hydrogen, Hδ, Hγ and Hβ, because these are the deepest and most reliable lines for redshift measurements. The radial velocity of 'bl1' is -79 ± 10 km s^{-1}, while radial velocity of 'bl2' is -76 ± 15 km s^{-1}.

In addition, we analyzed the redshifts of absorption hydrogen lines of the unresolved stellar populations integrated at various areas along the slits. These hydrogen lines are the most prominent details in the spectra of unresolved objects. The mean value of the radial velocity obtained from these spectra -86 ± 20 km s^{-1}, is in good agreement with the measured velocities of the two BSGs.

We also found a compact HII region exhibiting faint Hβ emission (see Fig. 2), as well as an extended region of faint diffuse [OIII]$\lambda 5007, 4959$ emission, located in the north-east part of the galaxy, traced over 70 pc along the first slit and over 120 pc in the second slit. We will present a more detailed analysis of the spectroscopic data in a follow-up work.

5 RESULTS AND DISCUSSION

The basic parameters of VV124 are presented in Table 1, based on our measurements and data available from the literature. As judged from our distance estimation and new photometric and spectroscopic measurements, VV124 lies at a distance of 1.1 Mpc and appears to be a transitional type dwarf galaxy: although possessing

Table 1. Properties of the VV124 dwarf

Parameter	Value	Reference
A_B	0.07	NED
B_T	13.68 ± 0.03	Taylor et al. (2005)
K_T	12.05	Grauer et al. (2003)
Size$_{25}$	$2'.1 \times 1.3$	HyperLeda
P.A.	$87°.5$	Leda
$(U-B)_T$	-0.08 ± 0.04	Taylor et al. (2005)
$(B-V)_T$	0.58 ± 0.04	Taylor et al. (2005)
$(B-R)_T$	0.85 ± 0.05	Jansen et al. (2000)
Distance (Mpc)	1.1 ± 0.1	this work
$[Fe/H]$	-1.37	this work
V_h (km s^{-1})	-80 ± 10	this work
V_{LG} (km s^{-1})	-22	this work
M_B	-11.6	this work
M_K	-13.2	this work
Size$_{25}$ (kpc)	0.67×0.41	this work

some young stellar populations the bulk of stars is evolved. Despite its isolated location, and some recent star formation, the properties of VV124 are clearly not those of a galaxy in formation.

VV124 is located 1.1 Mpc from the MW and 1.2 Mpc from M31 –on the periphery of the Local Group (Fig. 4). Leo A is its nearest neighbor, at a separation of $\simeq 0.5$ Mpc. There are only two other galaxies in the LG with similar, although slightly lower, degree of isolation: DDO 210 and SgrDIG, located in the direction opposite to that of VV124. Remarkably, the peculiar radial velocity of these three galaxies, corrected either for the LG rest frame or for the motion within the Local Sheet –following relation (15) from Tully et al. (2008)– is close to zero, $-22 < V_{LG} < +10$ and $-5 < V_{LSh} < +9$ km s^{-1}, confirming that these objects are near the LG turn-around radius. Most importantly, these galaxies are not, and have never been, satellites of either of the dominant members of the Local Group. Their free-fall time into M31 or the MW, is longer than a Hubble time. The exceptional isolation means that these are among the few galaxies in the nearby Universe which evolution have never been complicated by the local environmental mechanisms. Therefore, these objects are ideal probes of the basic mechanisms affecting the star-formation history of a galaxy. This would, however, require deeper observations, preferably with HST.

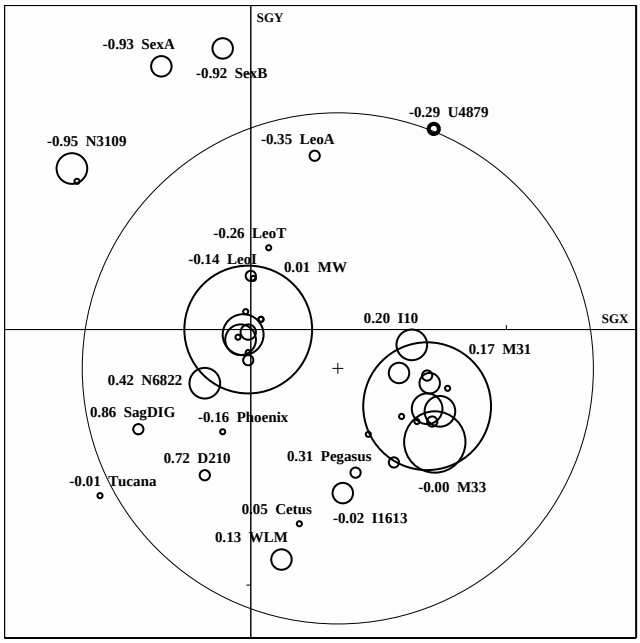

Figure 4. Updated map of the Local Group and its surroundings in Supergalactic SGX, SGY coordinates. The numbers show the SGZ-distance in Mpc to the SGXY-plane. The large circle of 1 Mpc radius is centered midpoint between the Milky Way and Andromeda, which are indicated with two 0.25 Mpc radius circles. VV124 (UGC4879) is visible in the upper right.

ACKNOWLEDGMENTS

Based on observations obtained with 6m BTA telescope (Special Astrophysical Observatory of Russian Academy of Sciences). We acknowledge the usage of Sloan Digital Sky Survey, and the HyperLeda, NED and SIMBAD databases. ID acknowledges the support from the IAC program P3/94 and the Spanish Ministry of Science and Technology grant AYA 67913.

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